INL/CON-13-28137
PREPRINT

Advanced Electron Microscopic Techniques Applied to the Characterization of Irradiation Effects and Fission Product Identification of Irradiated TRISO Coated Particles From the AGR-1 Experiment

Global 2013

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October 2013

ADVANCED ELECTRON MICROSCOPIC TECHNIQUES APPLIED TO THE CHARACTERIZATION OF IRRADIATION EFFECTS AND FISSION PRODUCT IDENTIFICATION OF IRRADIATED TRISO COATED PARTICLES FROM THE AGR-1 EXPERIMENT

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Preliminary electron microscopy of coated fuel particles from the AGR-1 experiment was conducted using characterization techniques such as scanning electron microscopy (SEM), transmission electron microscopy (TEM), energy dispersive spectroscopy (EDS), and wavelength dispersive spectroscopy (WDS). Microscopic quantification of fission-product precipitates was performed. Although numerous micro- and nano-sized precipitates observed in the coating layers during initial SEM characterization of the cross-sections, and in subsequent TEM diffraction patterns, were indexed as UPd_2Si_2, no Ag was conclusively found. Additionally, characterization of these precipitates highlighted the difficulty of measuring low concentrations of Ag in precipitates in the presence of significantly higher concentrations of Pd and U. The overlapping x-ray energies did not allow for determination of trace amounts of Ag or for accurate quantitative analysis of the fission product precipitate composition. AGR1 post irradiation examination electron microscopy to date also identified that precipitates in the SiC layer were located on the grain boundaries. The electron microscopy team followed a multi-directional and phased approach in the identification of fission products in irradiated TRISO fuel. The advanced electron microscopy techniques discussed in this paper, not only demonstrate the usefulness of the equipment (methods) as relevant research tools, but also provide relevant scientific results which increase the knowledge about TRISO fuel particles microstructure and fission products transport. The scanning transmission electron microscopy (STEM), TEM, electron back scattered diffraction (EBSD) and electron energy loss spectroscopy (EELS) results are the first of kind results on irradiated SiC layer of TRISO coated particles. Additionally, the application of transmission-EBSD (t-EBSD) is also recognized as the first application of its kind on any TRISO coated particles. Additionally, the STEM characterization provided the first of kind results of silver containing nano-sized triple-points and grain boundaries. This provides significant knowledge for silver transport mechanistic studies which has been the topic of international research for the past forty years.

I. INTRODUCTION

Preliminary electron microscopic characterization using scanning electron microscopy (SEM), transmission electron microscopy (TEM), energy dispersive spectroscopy (EDS), and wavelength dispersive spectroscopy (WDS) was performed on selected irradiated tristructural isotropic (TRISO) coated particles from the AGR-1 experiment at the Idaho National laboratory (INL). The characterization provided initial information on the presence of fission-product precipitates (Ref. 1). These precipitates were located on the SiC grain boundaries within the SiC layer and were also present in the inner pyrolytic carbon (IPyC) layer (Ref. 1).

Relatively high release of silver from some of the AGR-1 fuel compacts and particles (Ref. 2) accentuates the need to identify and measure silver in the SiC layer. The Ag transport mechanism through the SiC layer has not been conclusively identified after nearly 40 years, although recent research postulates that Ag transport may be driven by grain boundary diffusion (Ref. 3-6). It was also speculated in previous work (Ref. 1), that Ag would be able to substitute for Pd in a $U(Ag,Pd)_2Si_2$ solid solution rather than forming a separate phase since they have identical atomic radii (both 0.144 nm for the pure elements [Ref. 7]). Van Rooyen et al. (Ref. 4) speculated that it may be considered that the Ag transport mechanism cannot be attributed to a single factor, but rather to the combined effect of more than one factor. The initial electron microscopic examination on AGR-1 coated particles using SEM-EDS, SEM-WDS and TEM-EDS attempted to identify silver in the fission-product precipitates but was not successful. Although the WDS has much higher energy resolution than EDS, so that it potentially could distinguish between the overlapping peaks of Pd, U and Ag (the Ag Lβ X-ray is separated by 78 eV from the closest Pd X-ray and only 9.6 eV from the

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nearest U X-ray), the presence of Ag could not confirmed. Even TEM-EDS analysis using a new silicon-drift EDS detector with a normal 0-40 keV range did not yield conclusive evidence based on the higher-energy Ag Kα1 peak at 22.166 keV which avoided overlapping problems between U, Pd, and Ag.

The availability of the AGR-1 coated particles also provided a unique opportunity to determine the character of grain boundaries in the area of the precipitates as well as detailed chemical analysis using advanced techniques. Data from this type of analysis will provide information on the high angle grain boundary distribution to test recent grain boundary-Ag transport mechanism hypotheses by researchers (Ref. 8-10). In addition these data will allow for validation of Xiao et al.'s (Ref. 11) finding on the specific adsorption properties of the (001) surface of 3C-SiC.

In this paper, a brief summary of the specific advanced techniques and associated methods development applied on TRISO coated particles are given. Some preliminary scanning transmission electron microscopy (STEM), STEM-EDS, electron energy loss spectroscopy (EELS) and electron backscattered diffraction (EBSD) results obtained from selected irradiated fuel particles will be given as demonstration of the value of these methods for TRISO fuel performance. The two particles (AGR1-632-034 and AGR1-632-035) discussed in this paper retained a higher fraction of Ag-110m under irradiation than other particles in the hope that enough Ag would be present to be identified using these advance microscopic characterization techniques. These two particles were chosen based on gamma spectroscopy measurements (Ref. 1, 2). Compact 6-3-2 was irradiated to a 11.3% FIMA average burnup, 1070°C time-average, volume – average temperature; 1144°C time-average, maximum temperature and an average fast fluence of 2.38×10^{21} n/cm^2.

II. ADVANCED ELECTRON MICROSCOPY TECHNIQUES CURRENTLY APPLIED

The STEM and EELS analyses were conducted with a FEI Tecnai G^2 F30 STEM at the Center for Advanced Energy Studies (CAES) at INL, where low activity irradiated materials can be examined. The thin, FIB-prepared lamellas minimized irradiation dosage so that it was possible to utilize these advanced techniques for the irradiated TRISO coated particles. The EBSD measurements were collected at the Electron Microscopy Laboratory (EML) at the Materials and Fuels Complex (MFC) of INL using the Quanta 3D FEG FIB-SEM, using a EDAX/TSL Digiview precision camera and data analysis was completed with Omni software Version 5.31. This is currently the only facility at INL where the EBSD measurements on irradiated TRISO coated particles can be collected.

II.A. Scanning Transmission Electron Microscopy (STEM) and STEM- Energy Dispersive Spectroscopy (EDS)

The materials used for the coatings on the high temperature gas-cooled reactor fuel consist of relatively light elements such as graphite and silicon carbide (SiC). After irradiation, relatively heavy fission products migrated into these coatings. High Angle Annular Dark Field (HAADF) detector is best suited for characterization studies, easily differentiating between the pyrolytic graphite and SiC coatings as well as revealing the distribution of fission products. STEM mode discriminates only differences in atomic number (so-called Z-contrast imaging). This mode is most useful in the identification of small precipitates for further compositional analysis (Ref. 12).

Compositional analysis of small precipitates and second phases using transmission electron microscopy (TEM) with EDS requires two main characteristics – namely, a small electron probe (smaller than the feature under analysis) and the collection of an EDS spectrum suitable for quantification of the elements present. Technological advances in state-of-the-art TEMs have made it possible to form extremely small probe sizes. Particularly in the STEM mode, probe sizes around 1 nm or less are possible. In STEM imaging mode, a small electron probe is scanned across the sample and an image of the sample is built up pixel-by-pixel from information collected by the HAADF detector below the sample.

Generally, the time to collect an EDS spectrum with high signal-to-noise increases as the electron probe size decreases. However, when a high brightness, Field Emission Gun (FEG) electron source is used, the EDS spectrum collection time becomes reasonable. Furthermore, small particles and features may lie within the sample thickness (and not extend completely through it). In this situation, compositional information of the matrix will be collected with that of the feature of interest. Under these circumstances, compositional information will be qualitative at best. Even for large features it is often difficult to determine whether it spans the entire thickness of the sample or whether it is inclined within the sample causing compositional information from the matrix (either lying on top of or below the feature of interest) to be collected along with that of the feature of interest.

Sample fabrication for EDS analysis using STEM techniques is well known and may be accomplished by a number of different techniques including electropolishing,

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ion milling and focused ion beam (FIB) preparation. Although the FIB technique is time and labor intensive, it is the best preparation technique for TRISO coated particle research because of its ability to specifically target the area of interest. Additionally this technique provided fairly large thinned areas for TEM and STEM examination. An example of a FIB-prepared lamella is shown in Fig. 1.

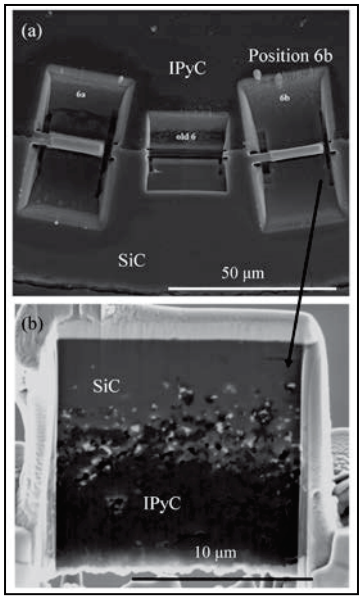

Fig. 1. Images showing a) the specific area of interest, position 6b, from AGR1-632-035 from which the FIB-lamella in b) was fabricated from.

STEM mode electron microscopy examination was conducted on this FIB-prepared sample and some examples are provided for demonstration purposes. The details of the STEM examination are discussed elsewhere (Ref. 13). Images in Fig. 2 were collected in the STEM mode using the HAADF detector on the Tecnai TF30-FEG STwin STEM, operating at 300 kV at the Center for Advanced Energy Studies. Fig. 2 shows an image in the SiC layer near the IPyC/SiC interface. The presence of heavy fission products (bright phase) is clearly evident as grain boundary phases and a dispersion of fine intragranular precipitates in the SiC matrix.

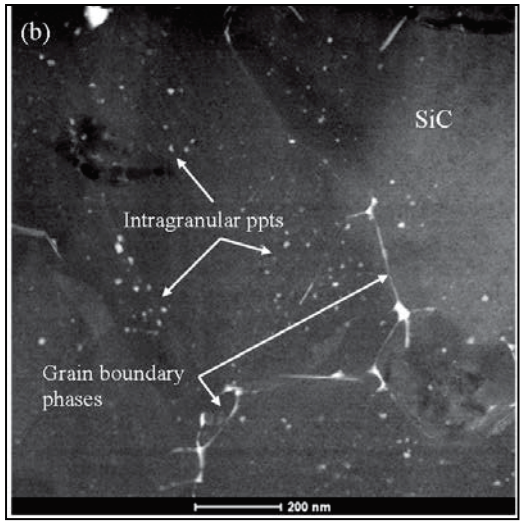

Fig. 2. STEM Micrograph of sample AGR1-632-035 position 6b showing fission products on the grain boundaries as well as fine precipitates in the interior of the grains.

Compositional information on the bright features can be obtained using the EDS detector and the small probe size available in the STEM mode. Generally, overlap of the elemental x-ray peaks is more of a problem at lower energies (approximately below 5 keV) where the L and M peaks of the various elements can be quite close together (Ref. 1). However, if attention is focused at the higher energies associated with K level transitions of the fission products it is possible to discern analysis points with high levels of silver, Fig. 3a, from analysis points with high levels of palladium, Fig. 3b. The palladium and silver Kα1 peaks are separated by approximately 1 keV (21.175 keV vs. 22.162 keV, respectively). (The uranium Lγ1 peak is located at 20.163 keV and also does not overlap the peaks of the fission products, Fig. 3b.)

As the features become small, substantial contributions to the EDS spectra from the matrix will be collected along with information of the feature of interest and only qualitative analysis of the EDS spectra will be possible. Furthermore, detection of low concentrations of fission products will require long collection times to differentiate their x-ray signal over background.

Figs. 3a and 3b show that even at counting times of ten seconds, the total counts in the silver and palladium peaks at high energies are still substantially less than 100. Sample drift at long counting times can lead to data collection away from the original area/point of interest. However, state-of-the-art STEMs, such as the Tecnai TF30-FEG STwin STEM, have drift correction software to keep the analysis point relatively constant but difficulties may still arise in the analysis of very small precipitates (less than about 10 nm) such as those shown

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in Fig. 2. Accurate quantitative analysis of small precipitates will be difficult due to the contribution of the matrix to the EDS spectrum.

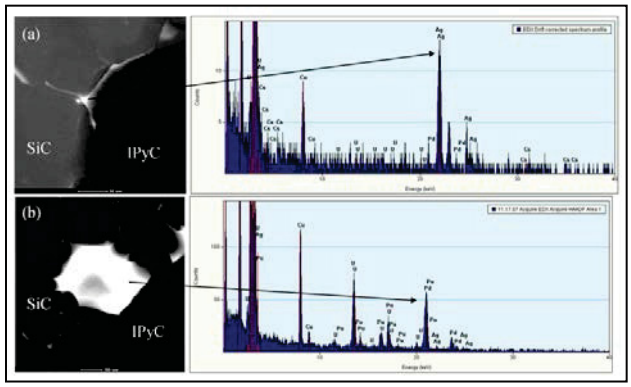

Fig. 3. a) EDS spectra on sample AGR1-632-035 position 6b showing overlap of EDS peaks of Zr, Pd, Ag, U and Si at low energies (<5 keV) while at higher energies (>20 keV) one can easily differentiate analysis points high in a) Ag in a grain boundary phase and b) Pd in one of the large, bright phases.

II.B. Electron Energy-Loss Spectroscopy (EELS) and Energy Filtered TEM (EFTEM)

In TEM, some incoming electrons lose energy when they travel through the specimen due to the inelastic interaction with specimen's atoms. EELS analyzes the energy distribution of these scattered electrons and provides quantitative compositional information about the nature of the atoms under illumination by the electron beam. The transmitted electrons can be filtered with respect to energy loss and only those electrons with a specific energy loss e.g. that associated with Ag can be chosen for imaging> In essence, these filtered electrons, with a selected energy loss, form an elemental map in the imaging mode (EFTEM).

EELS analysis is considered important for TRISO fuel research because of the specific resolution of elements if interest. In EELS analysis, the chemical sensitivity and the size of resolvable feature could be at 1% and smaller than 1 nm, respectively. Moreover, Pd, Ag and U have close but separable edge energies in an EELS spectrum, which suggests that trace amounts of Ag in the studied sample should be able to be detected using the EELS technique.

EELS/EFTEM requires thin TEM specimen. Additionally, the thin FIB prepared lamellas also reduce irradiation dosage below the operating envelope of the Microscopy and Characterization Suite (MaCS) at Center for Advanced Energy Studies. The EELS spectra showed in Fig. 4 shows the successful identification of Ag at a triple junction of grain boundaries. This result confirms the presence of Ag found by EDS analysis shown in Fig. 3.

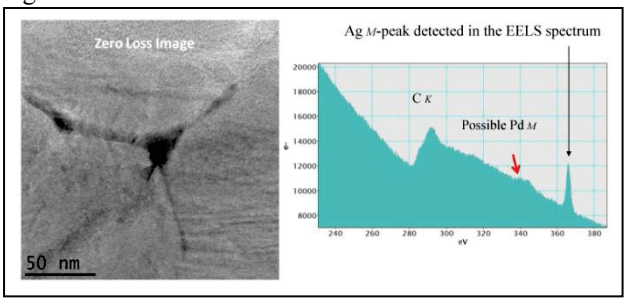

Fig. 4. Figure showing the EELS spectrum identifying the presence of Ag in the triple junction of SiC grain boundaries from sample AGR1-632-035 position 6b.

Typically, the challenges experienced can be classified as related to preparation or the location of the edge energies of the studied elements which may give challenges if they are close to each other. Commonly, the FIB-prepared TEM specimen may not be thin enough for ideal EELS/EFTEM analysis. Additionally in the case of TRISO coated particle research, the EFTEM elemental mapping of Ag and Pd may overlap since the edge energies of Ag $M_{4,5}$ (367 eV) is close to Pd $M_{4,5}$ (335 eV). However as can be seen from Figs. 4 and 5, the lamellas prepared at EML, were sufficiently thinned to obtain the EELS spectra and EFTEM maps.

EFTEM elemental mapping was done at four locations of the TRISO sample using the 3-window method at edge energies of Pd $M_{4,5}$ 335 eV, Ag $M_{4,5}$ 367 eV, U N_7 381 eV, C K 284 eV and Si $L_{2,3}$ 99 eV, respectively. Since the edge energies of Pd $M_{4,5}$, Ag $M_{4,5}$ and U N_7 are close to each other, the Ag map might contain Pd information and the U map might contain Ag information, respectively. At this moment these EFTEM maps are used only as complimentary information as shown in Fig. 5, but with further work on the three window energy settings, this may be more conclusive. This EFTEM method is of specific interest in this research, as it could provide a means of showing elemental distribution that would assist in understanding the transport of these elements or compounds.

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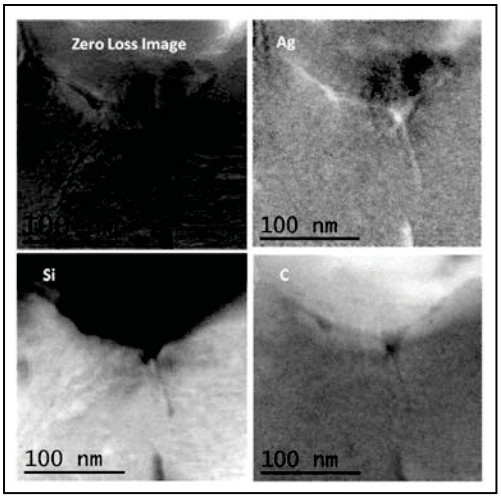

Fig. 5. Images showing the EFTEM maps. Although the Ag map provides images of Ag at the grain boundaries and triple junction, this map may not be used as conclusive evidence since energy window selection for the 3-window EFTEM method has not yet been optimized.

II.D. Electron Back Scatter Diffraction (EBSD)

EBSD is a practical characterization technique to obtain crystallographic information like crystal type, orientation, grain boundary characteristics, grain size distribution and texture. These measurements are obtained from small areas using a scanning electron microscope (SEM). The ability of this technique to perform scanning over a wide range of step sizes makes it possible to investigate the microstructure down to nano levels when needed (Ref. 14). As mentioned previously, data from this type of analysis provides details of the high angle grain boundary distribution to test recent grain boundary-Ag transport mechanism hypothesized by researchers (Refs. 8-10).

Although EBSD measurements on the unirradiated SiC layer of TRISO coated particles have been reported by various researchers (Refs. 6; 15; 16). Sample preparation quality is one of the largest challenges with small grained material and specifically with the differential removal rates of IPyC and SiC of the TRISO coated particles. The latter easily results in a rounding effect of the SiC at the SiC-IPyC interface which causes the EBSD analysis to be partially ineffective for fission product transport studies.

Preliminary comparative work on sample preparation techniques was reported on unirradiated SiC (Ref. 6). This study by Van Rooyen et al. (Ref. 17) described a new approach to the FIB preparation technique used previously by Kirchofer et al. (Ref. 9). In this modified FIB sample preparation technique, a thicker TEM lamella was prepared as shown in Fig. 6. The intial TEM-lamella-version of this technique resulted in vertically mounting the sample but a more recent modification resulted in horizontal mounting. Although the latter horizontal mounting technique still needs to produce EBSD data, it provides additional advantages when working with irradiated materials. It is expected that no extra handling will be necessary and standard grid holders can be used. This will substantially decrease the risk of exposure to the microscopist and the risk of losing a radioactive sample. As long collection times seems to be necessary for SiC, drifting may cause a loss of data. The modified horizontal mounting substantially decreases the possibility of drifting during lengthy data collection.

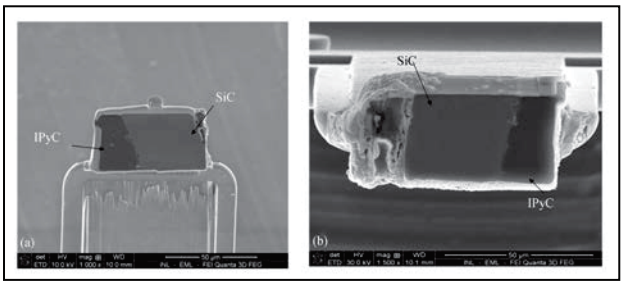

Fig. 6. Micrographs showing a) vertical and b) horizontal FIB prepared thick EBSD lamellas on irradiated SiC layers of TRISO coated particles of AGR1-632-034 and AGR1-141030 respectively.

SiC is a difficult material to image with EBSD without any crystallographic disruption due to irradiation damage, lattice strains and multiple polytypes of SiC present. With Si and C both being fairly light elements, the signal generated for EBSD collection is weak. The unirriadiated SiC materials that were examined previously possess fairly well preserved microstructures and are therefore measureable. However, as a crystal structure is stressed mechanically, by heat treatment or by neutron exposure, the Kukuchi patterns (lines) will become weak and as the material approaches an amorphous nature, the lines may not be existent at all. This behavior provides an additional challenge for the collection of EBSD data on irradiated SiC layers.

Data collection was acquired from a FIB prepared sample of AGR-1-632-034 and some selected images are provided in Fig. 7. It is clear from Fig. 7 that further improvements are necessary, but these initial images provide a baseline to work from. Clear grains are visible in secondary electron SEM images so current EBSD hardware limitations (e.g., camera) for this type of material are also being evaluated. It is hard to tell if the lack of well-defined EBSD patterns is an artifact of the detector type, SEM operating parameters, sample preparation, or material damage from irradiation.

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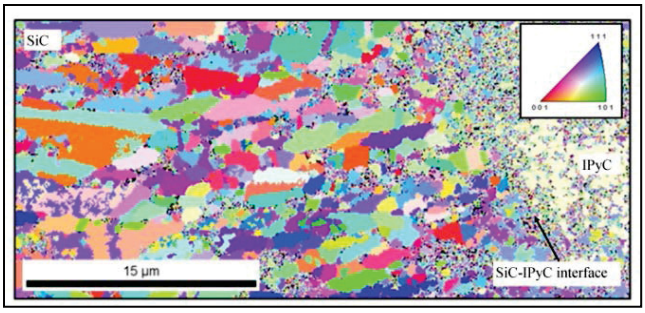

Fig. 7. Inverse pole figure (IPF) orientation map collected from a neutron irradiated SiC layer from sample AGR1-632-034 showing no preferred orientation.

III. ADVANCED ELECTRON MICROSCOPY TECHNIQUES FOR FUTURE RESEARCH

Additional advanced microscopic techniques, for example Transmission-EBSD (t-EBSD), atom probe tomography (APT) and high-resolution transmission electron microscopy (HRTEM), are being considered for TRISO coated particle research.

III.A. Transmission-EBSD (t-EBSD) (also called Transmission Kikuchi Diffraction (TKD))

EBSD has been the dominant method for obtaining crystallographic data within the SEM for decades. It is applicable to most crystalline materials except for ultrafine grained materials with grain/cell diameters smaller than ~100 nanometers. This limitation is based on EBSD technique's spatial resolution, which is a function of the backscattering coefficient of the analyzed material, the electron probe diameter and energy, and the incident angle between the beam and the specimen surface (~20º). While significant spatial resolution improvements can be achieved by decreasing the beam acceleration voltage and diameter there is still a multitude of nanomaterials that are very difficult or impossible to characterize using the EBSD technique.

TKD or t-EBSD is an SEM method for measuring crystallographic properties in materials, similar to EBSD, but with an order of magnitude improvement in spatial resolution. The resolution is better because of the forward-direction scattering that excites the electrons near the exit surface, where they have a chance for Kikuchi scattering. Forward scattering is of course favored in conventional EBSD as well, but in order to form a pattern, backscatter detection out of the beam entry surface is also required, and the backscatter signal is less compared to the transmission case. Another advantage of the forward-scatter (TKD) geometry is that because low-angle elastic scattering is favored over high-angle scattering, there is less beam-spreading in thin specimens by the time the important Kikuchi events occur. In addition, the interaction volume is considerably smaller.

TKD has been successfully applied to studies of nanoparticles, thin films and thinned foils obtained from bulk materials. Thus, all known TEM sample preparation methods will work. Incident beam energies in the 15 keV to 30 keV range can be used, along with probe currents in the range of a couple hundred picoamperes to a few nanoamperes. Dwell times for both point and mapping modes are typical of those used for reflection EBSD.

For initial exploratory work, t-EBSD measurements were performed on a non-irradiated FIB-prepared sample, TO-651-Sample 6, which represents the Variant 2 AGR-1 fuel which was fabricated with SiC deposition parameters similar to the Baseline fuel with changes only to the IPyC coating deposition parameters producing a less dense IPyC layer (see discussion of the AGR-1 fuel types in Ref. 9). The FIB–prepared sample was fabricated from the SiC layer in the radial direction just inside the SiC layer. The advantage of using a sample from this batch material is that EBSD results are available from work performed by Kirchofer et al. (Ref. 9) and can be used as comparison, although consideration needs to be taken to the differences in area of examination. In this paper only preliminary results are provided from the first t-EBSD measurements and comparative evaluation will be provided at a later stage after full optimization of the t-EBSD method. Once this technique has been successfully demonstrated on non-irradiated SiC, it will be applied to the irradiated SiC. The orientation map (IPF) overlapped with the pattern quality map (PQM) is shown in Fig. 8. No preferred orientation is observed in this area. Fig. 9 below shows the distribution of CSL boundaries (Σ3 and Σ27a) in blue and green respectively. The map was acquired using a step size of 8 nm. The results indicate that a high fraction of the boundaries are Σ3 boundaries. This information should only be considered qualitative as quantitative results will require less zero solutions near the grain boundaries. More measurements with improved spatial resolution will be required for a quantitative grain boundary analysis.

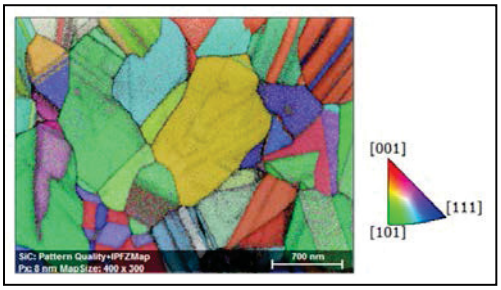

Fig. 8. Orientation map, (IPF), overlapped with Pattern Quality map (PQM).

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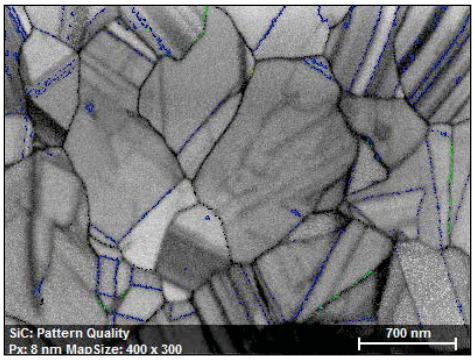

Fig. 9. PQM and grain boundaries map showing special Σ3 and Σ27a boundaries in blue and green respectively while all other grain boundaries are shown in black.

III.B. Atom Probe Tomography (APT)

Atom probe tomography (APT) is the only microstructural characterization technique that can reconstruct both atom position and chemistry with atomic resolution in three-dimensional (3D) space. In this technique, high voltage is applied to a needle-like specimen (~50 nm tip diameter). Atoms at the tip are ionized with applied voltage pulse or laser pulse due to high electric field, and then the ions are detected by a position-sensitive detector positioned in front of specimen. Atom identity can be determined by time-of-flight mass spectrometry technique. Therefore, both atom position and chemistry can be determined and reconstructed in real 3D space with atomic resolution. Fig. 10 gives a comparison between a typical APT data size (red-line covered area) and TEM field of view, indicating that information from APT comes from an extremely small area.

Fine features in the studied samples are on the nanometer scale as previously shown in Figs. 1 to 3. The concentration of some elements, e.g., Ag, could be very low. In APT analysis, the chemical sensitivity and the size of resolvable feature could be lower than 100 ppm and smaller than 1 nm, respectively. More importantly, unlike other techniques, APT has no elemental limitation. The elements, Pd, Ag, U, Eu and Cs, in the studied system can be easily identified and analyzed using ATP because they do not have overlapping peaks in mass spectrum.

APT samples are prepared using the lift-out technique in the FIB which is available at the EML facility. It is typically possible to fabricate approximately 5 -8 tips within one work day. As seen in Figure 10, the field of view of APT data is quite limited at nanoscale. Therefore, it could be difficult to obtain specific features of interest. Multiple specimen tips are usually prepared to increase the chance of obtaining useful information.

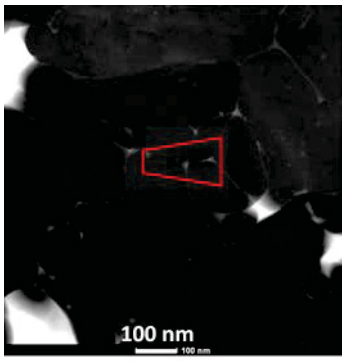

Fig. 10 STEM image of the studied sample. The red-line covered area represents the size of a typical APT data.

III.C. High Resolution Transmission Electron Microscopy (HRTEM)

HRTEM is an imaging mode of the TEM that allows the imaging of the crystallographic structure of samples at an atomic scale. Under correct operating conditions and well-prepared samples, high-resolution image characteristics are interpretable directly in terms of projections of individual atomic column positions. HRTEM studies envisioned for the SiC layer of TRISO coated particles require an approximate focal spread of 3.9 nm with an interpretable resolution better than 0.1 nm. This will provide the imaging and orientation on the interface between the precipitates and the relevant SiC grain and/or the IPyC layer. EELS will then be able to be measured on specific atom groups, which will provide more information on transport mechanisms. Specifically also the further examination of Ag in the triple-junctions and nano-sized grain boundaries as discussed in Section II.A., will benefit using HRTEM for further studies.

IV. CONCLUSIONS

The electron microscopy team followed a multi-directional and phased approach in the identification of fission products in irradiated TRISO fuel. The advanced electron microscopy techniques discussed in this paper, not only demonstrate the usefulness of the equipment (methods) as relevant research tools, but also provide relevant scientific results which increase the knowledge about TRISO fuel particles microstructure and fission products transport.

The STEM, TEM, EBSD, t-EBSD and EELS results are the first of kind results on irradiated SiC layer of TRISO coated particles reported in open literature. Additionally, the STEM examination provided the first of kind results indicating silver containing nano-sized triple-points and grain boundaries. This provides significant knowledge for silver transport mechanistic

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studies which has been the topic of international research for the past forty years.

The t-EBSD technique is considered for TRISO coated particle research in parallel to the initial scoping EBSD studies on irradiated SiC. This technique may provide advantages not only in decreased sample preparation time, but also in the quality and resolution of results needed for irradiated SiC. This will also provide a direct means to measure the grain characteristics at the exact location where fission product precipitates were identified using the STEM, EELS and EDS technique. Additionally, this will provide the opportunity to use other SEM facilities with higher resolution (higher speed) EBSD cameras to further enhance the quality of mages obtained.

ACKNOWLEDGEMENTS

This work was sponsored by the U.S. Department of Energy, Office of Nuclear Energy, under DOE Idaho Operations Office Contract DE-AC07-05ID14517. David Petti and Paul Demkowicz are thanked for the review of this document.

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